NPS 62-88-013

NAVAL POSTGRADUATE SCHOOL

Monterey, California

A CAD MODEL FOR
THE INDUCTIVE STRIP IN FINLINE

Jeffrey B. Knorr

August 1988

Final Report for the Period
1 July 87 - 31 March 88

Approved for Public Release; Distribution is Unlimited.

Prepared for:

Naval Postgraduate School
Monterey, CA 93943

NAVAL POSTGRADUATE SCHOOL
MONTEREY, CALIFORNIA 93943

The work reported herein was supported in part by the Naval Postgraduate School during the author's sabbatical leave.

This report was prepared by:

UNCLA

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a REPORT SECURITY CLASSIFICATION: UNCLASSIFIED

1b RESTRICTIVE MARKINGS:

2a SECURITY CLASSIFICATION AUTHORITY:

2b DECLASSIFICATION / DOWNGRADING SCHEDULE:

3 DISTRIBUTION / AVAILABILITY OF REPORT:

4 PERFORMING ORGANIZATION REPORT NUMBER(S): NPS-62-88-013

5 MONITORING ORGANIZATION REPORT NUMBER(S):

6a NAME OF PERFORMING ORGANIZATION: NAVAL POSTGRADUATE SCHOOL

6b OFFICE SYMBOL (If applicable): ECE, CODE 62

7a NAME OF MONITORING ORGANIZATION: NAVAL POSTGRADUATE SCHOOL

6c ADDRESS (City, State, and ZIP Code): Monterey, CA 93943

7b ADDRESS (City, State, and ZIP Code): Monterey, CA 93943

8a NAME OF FUNDING / SPONSORING ORGANIZATION: Naval Postgraduate School

8b OFFICE SYMBOL (If applicable):

9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER:

8c ADDRESS (City, State, and ZIP Code): Monterey, CA 93943

10 SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO	PROJECT NO	TASK NO	WORK UNIT ACCESSION NO

11 TITLE (Include Security Classification)

A CAD MODEL FOR THE INDUCTIVE STRIP IN FINLINE

12 PERSONAL AUTHOR(S): JEFFREY B. KNORR

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
FINAL	FROM 1 Jul 87 TO 31 Mar88	AUGUST 1988	33

16 SUPPLEMENTARY NOTATION

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

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20 DISTRIBUTION / AVAILABILITY OF ABSTRACT: ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS

21 ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED

22a NAME OF RESPONSIBLE INDIVIDUAL: JEFFREY B. KNORR

22b TELEPHONE (Include Area Code): (408) 646-2815/2082

22c OFFICE SYMBOL:

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE

☆ U.S. Government Printing Office: 1986—606-24.

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by
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ABSTRACT

This report describes a CAD compatible circuit model for an inductive strip centered in finline with $W/b=E_{r2}=1$. The circuit model is shown to predict strip scattering coefficients which agree closely with those measured experimentally in X-band. By application of the scaling principle the model is generalized for use with any waveguide size over the normal frequency range for the dominant TE_{10} mode.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the support provided by the Naval Postgraduate School for a Sabbatical Leave during which time this work was accomplished. The contributions of several of the author's graduate students is also acknowledged as their work with me provided the basis for this modeling effort. The students and their contributions are identified in the body of this report.

LIST OF FIGURES

LIST OF TABLES

TABLE OF CONTENTS

I. INTRODUCTION

A. BACKGROUND

Finline is a transmission structure which was first described by Meier in 1974 [1]. Figure 1 shows a cross-sectional view of a finline. In its most general form, it consists of metal fins printed on a dielectric substrate which is mounted in the E-plane of a rectangular waveguide. The dielectric substrate is normally used only to support the metal fins. It is typically thin and has a low dielectric constant. In some situations fin circuit structures can be printed using metal without dielectric. Since its introduction in 1974, finline has been used extensively, especially in millimeter wave applications.

The successful application of any transmission structure requires the availability of data describing the behavior of transitions, discontinuities, coupled lines, etc., all of which must be understood if circuits are to be designed. The data may be measured experimentally, computed numerically or generated using appropriate circuit models. Today, it is particularly desirable to have models which are compatible with the CAD process. They must be fast, accurate and efficient to be useful.

The inductive strip is an important finline discontinuity. It is the principal element required for the design of finline filters. Figure 2 shows two finline resonators which are coupled by an inductive strip. A filter consists of a number of resonators coupled together by inductive strips with input and output to finlines. The filter transfer characteristic is controlled by properly choosing the number of resonators, their lengths and the lengths of the inductive strips which couple them together.

In the most general case, an inductive strip spans the space between the fins of a line with arbitrary W/b and E_{r2} (see Figs. 1 and 2). To achieve high Q in a filter, however, losses must be minimized. Finline losses can be reduced by choosing $W/b=E_{r2}=1$ (no dielectric). We are then left with an axial strip between the top and bottom walls of a rectangular waveguide (E-plane strip). Bandwidth considerations then dictate that the strip be centered if the finline is unilateral. Thus, the centered strip with $W/b=E_{r2}=1$ represents a special but very important practical case for the design of high Q finline filters.

B. RELATED WORK

Finline and the inductive strip in finline have been studied extensively in our laboratory. The first complete analysis of finline using the spectral domain method was published by Knorr and Shayda in 1980 [2]. Miller described experimental measurements of scattering coefficients of inductive strips and published data in his thesis in December 1980 [3]. The problem of a shorting septum in a finline is closely related to that of an inductive strip from an analytical point of view. A 1981 paper by Knorr presents experimental and numerical data for a shorting septum [4]. Lastly, experimental and numerical results for inductive strips were published by Deal in his M. S. thesis in March 1984 [5] and by Knorr and Deal in October 1985 [6].

Insights gained in the course of the work described above suggested that it might be possible to develop a useful equivalent circuit model for the finline inductive strip. A goal of compatibility with existing microwave circuit simulators was set. The objective was to develop a simple model which could be used with existing CAD software to design finline filters.

C. PURPOSE

The purpose of this report is to describe the development of a circuit model for an inductive strip centered in a unilateral finline with $W/b=E_{r2}=1$.

Section II of this report discusses the related work by Miller and Deal in more detail. Section III describes models for particular strips in WR(90) guide and then the extension of these results to realize a model for strips of arbitrary length. Section IV describes the application of the model to the design of a 3 resonator (4 strip) filter in WR(90) waveguide and presents a comparison of the response predicted by the model and the measured response. Section V describes how the WR(90) strip model can be extended to shields of arbitrary size. Lastly, Section VI presents some conclusions and ideas for future pursuit.

II. REVIEW OF RELATED WORK

The development of a circuit model like the one described in this report requires that numerical or experimental data be available for determination of model parameters. The work of Miller [3], Deal [5] and Knorr and Deal [6] provides a basis for development of the model for an inductive strip in finline. Miller presents experimental scattering coefficient data for inductive strips centered in WR(90) guide with no dielectric. Deal and Knorr and Deal discuss solution of the problem of the inductive strip in its most general form using the spectral domain method. Numerical data generated using a program written by Deal agrees well with experimental data reported by Miller as well as additional experimental data obtained by Deal. It should be possible, therefore, to use Deal's program to generate data for further model development although it should be noted that computation time is not insignificant.

The experimental data reported by Miller was used to develop the model described in this report. Figure 3 shows a summary of best fit curves to data for $/s_{11}/$ for strips of different lengths as reported by Miller. Figure 4 shows the corresponding data for θ_{11}, the angle of s_{11}. In all cases, the strips were centered in WR(90) guide with W/b=1 and E_{r2}=1. These figures were taken directly from Miller's thesis. Our goal will be to have the proposed circuit model accurately predict these data.

III. MODEL CONCEPT

The problem of constructing an equivalent circuit for a discontinuity in a transmission structure is a challenging one. It is not difficult to construct a lumped equivalent circuit which is correct at a single frequency. The literature is full of examples [7], [8]. The problem with these equivalent circuits is that although the equivalent circuit topology generally remains the same over some frequency range of interest, the values of the lumped elements change with frequency. This problem is usually addressed by providing curves of lumped element reactance vs. frequency (we assume here the discontinuity is lossless). A set of curves is then required for different values of the geometrical parameters of the discontinuity. It is much more difficult to construct a simple equivalent circuit which correctly predicts the scattering coefficients of a discontinuity over a specified frequency band when the values of the elements are fixed. Element values will still change if the geometry of the discontinuity is altered and the determination of some simple analytical expression describing the relationship between electrical parameters and geometry further complicates the problem.

The discontinuity of interest here is the inductive strip in finline as illustrated previously in Figure 2. Only centered strips in finlines with $W/b=E_{r2}=1$ will be considered here (see Figure 1). The proposed equivalent circuit is shown in Figure 5. It consists of two sections of below cutoff waveguide representing the spaces between the strip and the side walls of the shield and 2 lumped inductors which account for the discontinuity effect produced by the edges at each end of the strip. At this time it is possible to say only that this equivalent circuit was deduced based on intuition along with accumulated experience and insights gained during the course of our experimental and numerical investigations of inductive strips in finline.

The final justification for the use of any model is its ability to accurately predict what one would observe experimentally. Thus, the scattering coefficients predicted by the model illustrated in Figure 5 were compared with those measured experimentally for strips of length T=20, 50, 100, 200, 500, and 1000 mils in WR(90) waveguide over the 8-12 GHz band. For each strip length, it was found that there was a fixed value of shunt lumped inductance, L, which resulted in very good agreement between the measured and predicted values of s_{11}. The electrical behavior of the parallel below cutoff waveguide sections is completely determined by the dimensions a/2xbxT and frequency through the usual waveguide/transmission line relations

$$Z_{ov} = j(4b/a)120\pi[(f_c/f)^2 - 1]^{-1/2} \quad (f_c=c/a) \qquad (1)$$

$$Z = Z_o[Z_o + Z_L \tanh l]/[Z_L + Z_o \tanh l] \qquad (2)$$

Scattering coefficients are computed relative to a normalizing impedance

$$Z_{ov} = (2b/a)120\ [1 - (f_c/f)^2]^{-1/2} \qquad (f_c = c/2a) \qquad (3)$$

which is the voltage power impedance for the TE_{10} mode in the unloaded waveguide.

The comparison between measured scattering coefficients and those predicted by the model illustrated in Figure 5 were made using the TOUCHSTONE microwave circuit simulator marketed by EEsof, Inc., Westlake Village, CA. The measured scattering coefficients given by Miller were used to create TOUCHSTONE data files for each strip. A TOUCHSTONE circuit file was created to compute the scattering coefficients of the circuit model.

A. MODELS FOR STRIPS OF PARTICULAR LENGTHS CENTERED IN WR(90) WAVEGUIDE

As an example, consider a strip of length T=100 mils. The data file containing the measured scattering coefficients is shown in Figure 6. The circuit file ST100MOD.CKT which describes the model for the strip is shown in Figure 7. The file plots both the measured and predicted values of s_{11}. It should be noted at this point that if a two port network is lossless, reciprocal and symmetric that

$$/s_{21}/ = [1 - /s_{11}/^2]^{1/2} \qquad (4)$$

$$\theta_{21} = \theta_{11} \pm \pi/2 \qquad (5)$$

$$s_{22} = s_{11}. \qquad (6)$$

For an inductive discontinuity we choose $\theta_{21} = \theta_{11} - 90$ degrees so the scattering matrix of the inductive strip is completely determined from a knowledge of s_{11}. Therefore, we will compare measured and predicted values of s_{11} only. If these agree closely, so will the measured and predicted values of s_{21}. Figures 8-10 show a Smith Chart plot of measured and predicted s_{11} (8-12 GHz band), a plot of $/s_{11}/$ vs frequency and a plot of θ_{11} vs. frequency for the T=100 mil strip in WR(90) waveguide. The objective here is to adjust the value of L to obtain the best possible agreement between the measured and computed data. This raises a question as to wether this should be done using magnitude data, angle data or both. If a finline resonator is constructed from two identical inductive strips, the resonant frequency is determined by the strip spacing and θ_{11} while the Q is determined by $/s_{11}/$. θ_{11} seemed to be the more critical of the two parameters so it was decided to choose L for best agreement between measured and predicted values of θ_{11}. For Figures 8-10, L=20 nH was used. It is evident that the best fit to θ_{11} strategy resulted in very good agreement between measured and predicted values of $/s_{11}/$ also. Both magnitude and angle data agree to within about 2-3% which is within the range of uncertainty for the measured data.

The initial strategy was to find a value of L (see Fig. 5) which matched model data to measured data for each of the inductive strips in WR(90) waveguide. Table 1 summarizes the results.

Strip Length T in mils	Inductance L in nH
20	27
50	23
100	20
200	17
500	16
1000	16

Table 1. Model inductance L for inductive strips of various lengths T centered in WR(90) waveguide.

Smith Chart plots of measured and predicted values of s_{11} were generated for each of the experimentally studied inductive strips. Similarly, plots of measured and predicted values of $/s_{11}/$ and θ_{11} vs. frequency were generated for the frequency range 8-12 GHz. Examination of this data showed very close agreement between measured and predicted values when the model inductance L was assigned the values listed in Table 1.

B. EXTENSION TO STRIPS OF ARBITRARY LENGTH CENTERED IN WR(90) WAVEGUIDE

Having obtained good results for the particular strips modeled in the previous section, it is a simple matter to explore the possibility that the curve L(T) can be approximated by some simple analytical expression. Figure 11 shows a graph of the model inductance, L, as a function of the strip length T. The values listed in Table 1 are circled on the graph. A good fit to these data is the exponential curve

$$L = 16 + 14.4*EXP(-T/75) \text{ nH} \tag{7}$$

where strip length T is in mils.

The TOUCHSTONE circuit model was modified to permit T to be varied with L changing as described by Eq. 7. Figures 12-14 show a Smith Chart plot of s_{11}, a plot of $/s_{11}/$ vs. frequency and a plot of θ_{11} vs. frequency respectively for strips of length T=20, 50, 100, 200 and 500 mils. Agreement with previous results was found to be nearly exact when the data in Figures 12-14 were compared with the data previously computed for the individual strips. The model data given in Figures 13-14 may also be compared with the corresponding experimental data from Miller, shown in Figures 3-4.

This completes the development of the model for strips centered in WR(90) waveguide.

IV. APPLICATION TO CAD OF FINLINE FILTERS

One of the principal applications of the circuit model of the inductive strip in finline should be to the design of finline filters. Thus it seemed that a good check on the accuracy and utility of the model could be obtained by using it to design some filters and then comparing the measured and predicted performance of the filters.

A. MODELING OF A FINLINE RESONATOR

A finline resonator was previously investigated by Knorr and Deal. The resonator insertion loss and return loss were measured experimentally and also computed using strip scattering coefficients derived numerically from Deal's program. The results were reported in [6]. This published data provided an easy opportunity to check the inductive strip model described in this report.

The resonator consisted of two inductive strips of length T=220 mils separated by 530 mils in a WR(90) waveguide. The resonator was modeled using TOUCHSTONE. Figure 15 shows the insertion loss and return loss of the resonator as reported in [6]. It can be seen that the insertion loss response computed using the numerical scattering coefficient values agrees well with the experimentally measured insertion loss. Figure 16 shows the insertion loss and return loss computed using the circuit model described here with TOUCHSTONE. Unfortunately, the scaling is slightly different and this prevents overlaying the two Figures but a point by point comparison reveals that the agreement is excellent. The greatest discrepancy which appears is the difference in the resonant frequencies as indicated by the minima in the return loss curves. The difference is about 40 MHz which is 0.4%. Other than this, the curves are virtually identical.

B. DESIGN OF A FINLINE FILTER

A second test of the circuit model for the inductive strip was carried out by designing a finline filter. The design was done by coupling together three 10 GHz, high Q resonators and then adjusting the strip and resonator lengths to obtain a response which was approximately equal ripple centered at 10 GHz. This was accomplished using the TOUCHSTONE tune mode. The final configuration was achieved quickly and it should be emphasized that no particular effort was expended here since the objective was to compare measured and predicted filter responses and any filter would serve the purpose.

The final configuration was a symmetric filter with 4 strips and 3 resonators. The outside strips had length T=85 mils and the inside strips T=250 mils. The end resonators had a length of 560 mils and the center resonator was 552 mils long. The return loss and insertion loss of this filter are shown in Figure 17.

The fin structure required to fabricate this filter was cut from a 2 mil thick sheet of beryllium copper using an Exacto knife. The fabrication technique was less than elegant but it was fast and served the purpose. As expected, hand cutting of the fin structure resulted in dimensions which were in error by as much as 20 mils in the worst case. The dimensions of the actual fin structure were measured and the filter simulation was modified accordingly. Dimensions were T1=90, R1=558, T2=250, R2=540, T3=240, R3=540, T4=90. A photograph of the filter is shown in Figure 18.

The response of the fabricated filter was measured and compared with that predicted using TOUCHSTONE. Figure 19 shows the measured response and Figure 20 shows the predicted response. Both the insertion loss and the return loss curves are in very good agreement. The asymmetry created during the fabrication process can be seen in both the measured and predicted response. The most significant discrepancy is in the passband insertion loss. The measured insertion loss in the passband is small but noticeably greater than the loss predicted by the model. The small differences which can be seen in the return loss curves could be due to reflections from transitions and connectors. The filter shown in Figure 18 was connected to coaxial measurement equipment through waveguide-coax transitions and APC-7 connectors. Small reflections occurring at the resulting discontinuities corrupt reflection data, especially in regions where the filter reflection coefficient is small. No attempt was made here to investigate sources of experimental error. It is worth noting, however, that considerable attention was devoted to questions of accuracy and experimental error during the measurement of strip scattering coefficients upon which the development of the model for the inductive strip is based.

V. GENERALIZATION TO SHIELDS OF ARBITRARY SIZE

The inductive strip model described previously was derived for strips in WR(90) waveguide with $W/b=E_{r2}=1$. It is clear, however, that scattering coefficients

1. should be independent of waveguide height, b
2. should vary with strip length as T/a
3. should vary with frequency as $f/f_c = \lambda_c/\lambda$

where f_c is the waveguide cutoff frequency and $\lambda_c=2a$ is the guide cutoff wavelength. The scattering coefficients are dependent on the normalized inductive reactance,

$$\omega L/Z_{ov} = 2\pi f[16 + 14.4*EXP(-T/75)]/(2b/a)120\pi[1 - (f_c/f)^2]^{-1/2} \quad (8)$$

so this quantity must be put in a form in which the above three criteria are met. We therefore require

$$\omega L \propto (f/f_c)(b/a) = (\lambda_c/\lambda)(b/a) = (2a/\lambda)(b/a) \propto bf \quad (9)$$

or

$$L \rightarrow (b/400)L \quad (10)$$

and

$$T/75 \rightarrow (T/a)(900/75) = (12T/a). \quad (11)$$

This leads to

$$L = (b/25)[1 + 0.9*EXP(-12T/a)] \quad nH \quad (12)$$

where all dimensions are in mils. With this expression for L, we can now generate scattering coefficients for strips of arbitrary length in waveguides of arbitrary size.

As an example of the application of the generalized result, consider a WR(12) waveguide which covers the 60-90 GHz band. This guide has a=122 mils and b=61 mils. Strip widths in the range $0.02 < T/a < 1$ are required for filter design. Scattering coefficients for this range are shown in Figure 21. A 75 GHz finline resonator in WR(12) waveguide was designed and Figure 22 shows the response for strip widths T=30 mils and T=50 mils. The earlier discussion of the effect of $/s_{11}/$ on Q is verified by these results which show the Q increasing as we change T from 30 to 50 mils. In each case the strips were separated by 72 mils and this distance was chosen to center the resonance at 75 GHz. It is clear that the model described here has wide application and can be used for filter design throughout the microwave and millimeter wave bands.

VI. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

This report describes a circuit model for an inductive strip centered in a finline for the special, but important practical case $W/b=E_{r2}=1$. The model is elegant in its simplicity, consisting of parallel, below cutoff waveguide sections with lumped inductors at each end. The value of lumped inductance was determined by varying L to obtain the best agreement between the value of θ_{11} (the angle of s_{11}) predicted by the circuit model and the value of θ_{11} measured experimentally for strips of various lengths in WR(90) waveguide. Adjusting L in this manner resulted in very good agreement between measured and predicted values of $/s_{11}/$ as well. This procedure revealed that L varied exponentially with strip length, T. Thus, a simple model developed naturally from an investigation of inductive strips centered in WR(90) waveguide.

The demonstration of agreement between measured and predicted scattering coefficients is really adequate justification of the accuracy of the model. However, alternative demonstration of the validity of any model serves to instill confidence in its use. Thus, the model was used to design an X-band finline filter and it was shown that the measured and predicted filter response (return loss and insertion loss) were in excellent agreement.

Lastly, the results were put in a more general form by application of the scaling principle. The final result then is a circuit model for the inductive strip centered in a waveguide of any width and height. The model is valid for very thin strips (t=2 mils, t/a=0.0022 in X-band) over the normal operating band for the dominant TE_{10} mode. The model was developed using data for strips with length T=20 mils to T= 1000 mils or a normalized length range $0.022 < T/a < 1.1$ in X-band. There should be no problem with extension of the upper limit but it seems unwise to extend the lower bound below the strip length t=2 mils. The corresponding value of T/a will vary according to waveguide size. Bandwidth, of course, places some restrictions on the relationship between guide width and height. It is to be expected that normally $b < a/2$.

B. RECOMMENDATIONS

As a result of the success achieved in the modeling effort reported here, there are several areas which appear fruitful for future pursuit.

1. Develop a model for strips centered in finline with $W/b < 1$, $E_{r2}=1$.

2. Investigate the effect of strip thickness and modify the model to account for this effect.

3. Develop a model for inductive strips which are off-center with $W/b < 1$, $E_{r2}=1$.

4. Develop a model for the general case of a strip printed on a dielectric substrate with $W/b < 1$.

5. Determine the lower limit of T/a for which the model is valid.

It would be very useful to model centered strips with $W/b < 1$, $E_{r2}=1$ and this should be a straightforward task. Strip thickness will become a factor which must be considered at higher frequencies. Here, a thickness $t=2$ mils in WR(90) was used. Thus, $t/a=0.0022$ and the model should be quite accurate if t/a is close to this value. It should be a simple matter to modify the model to account for the effect of increasing t/a but data will be required. Off center strips is a less practical situation and the general case of a strip printed on a dielectric substrate will be the most difficult to model.

It would be interesting and useful to investigate the lower limit of T/a for which the model is valid. When the strip length T is equal to the thickness t ($T=t$) we have a rectangular wire across the waveguide. The problem of a round wire across a waveguide has been studied theoretically [7] and some comparison of results should be possible. Alternatively, additional experimental data could be obtained by making measurements but very short strips are fragile and difficult to fabricate without a dielectric substrate for support. Perhaps measurements on a 2 mil wire would be sufficient.

The model described here was developed using X-band experimental data and was then generalized for use with any size waveguide by applying the scaling principle. It has been validated in X-band but not in any other waveguide bands. The model should be used to design some millimeter wave filters or alternatively, should be checked against some millimeter wave strip scattering data to verify its accuracy in this frequency range.

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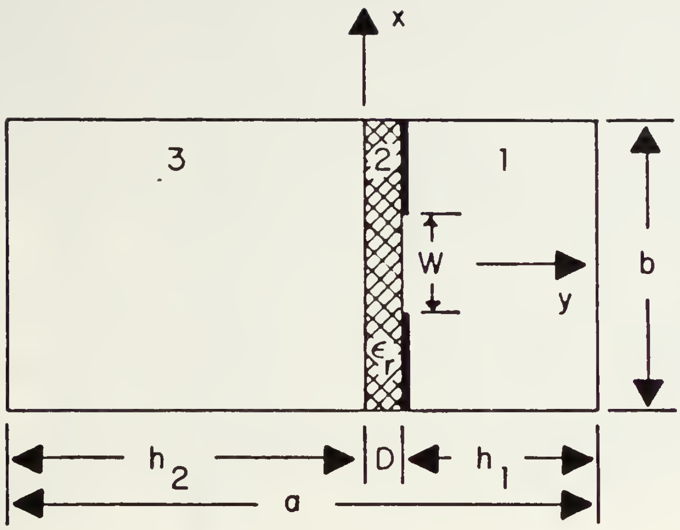

Figure 1. Cross-sectional view of a finline.

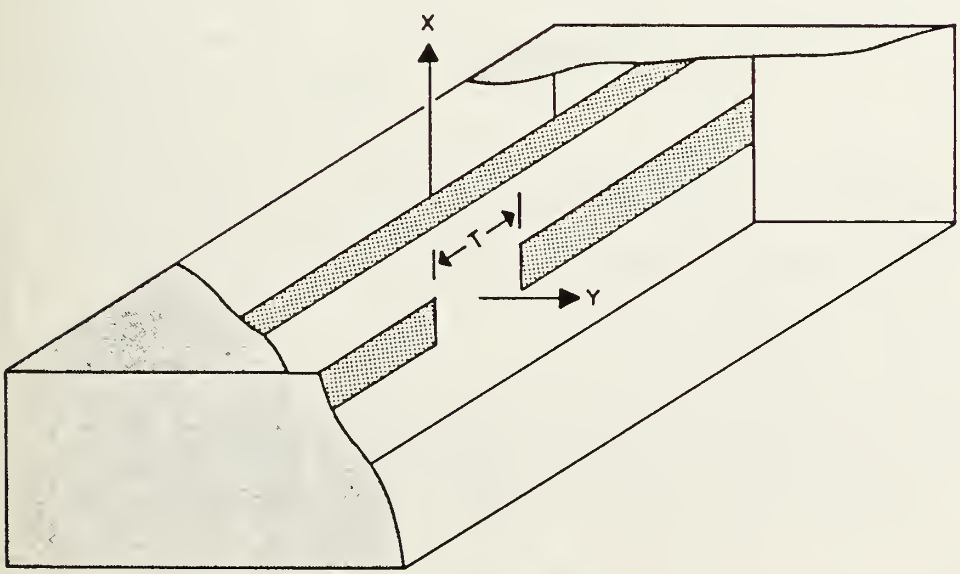

Figure 2. View of a finline inductive strip of axial length T centered in a finline cavity.

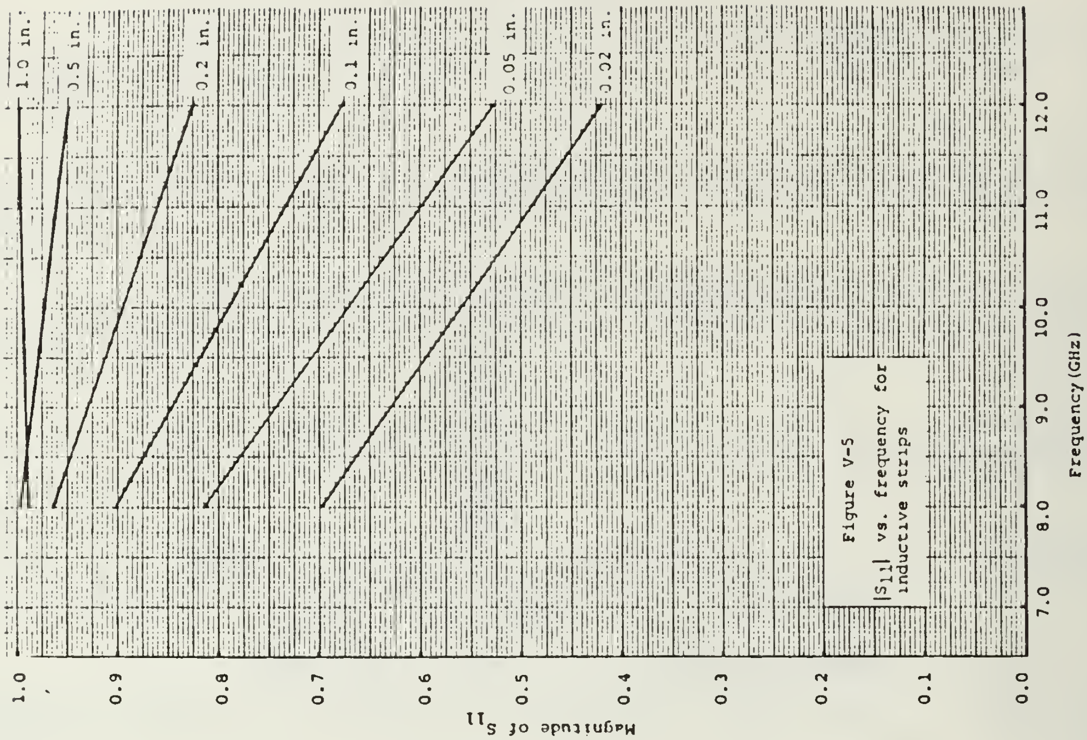

Figure 3. $/s_{11}/$ vs. frequency for inductive strips in WR(90) guide. W/b=1, E_{r2}=1, h_1=a/2. (From Ref. [3].)

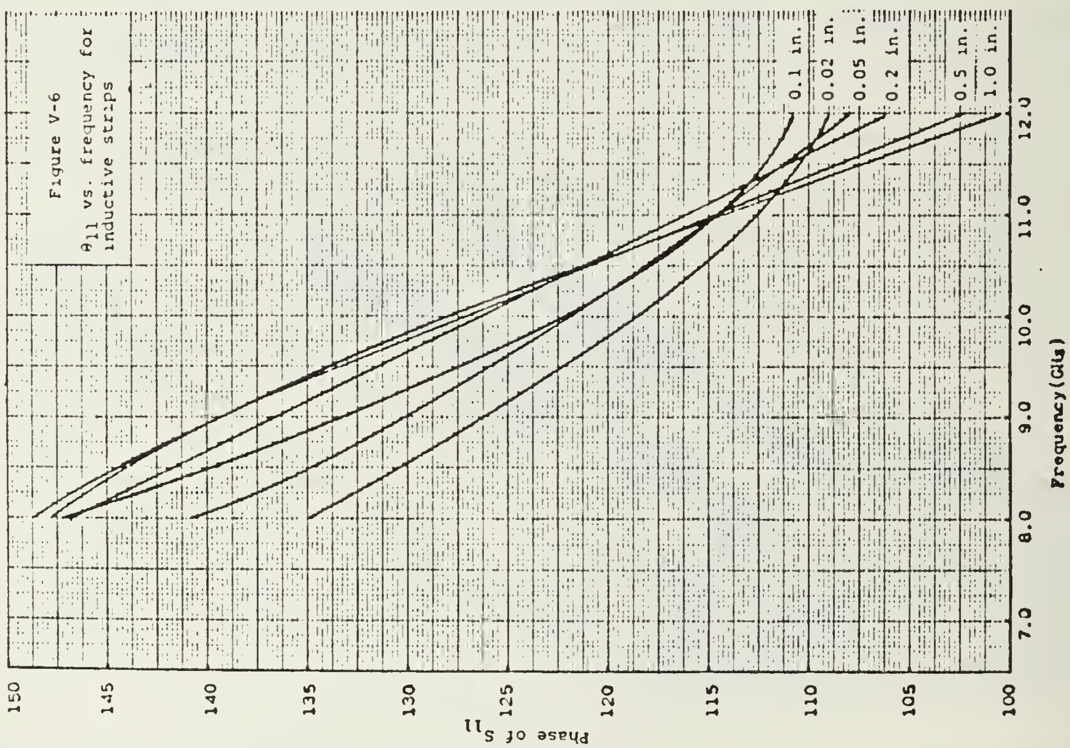

Figure 4. θ_{11} vs. frequency for inductive strips in WR(90) guide. W/b=1, E_{r2}=1, h_1=a/2. (From Ref. [3].)

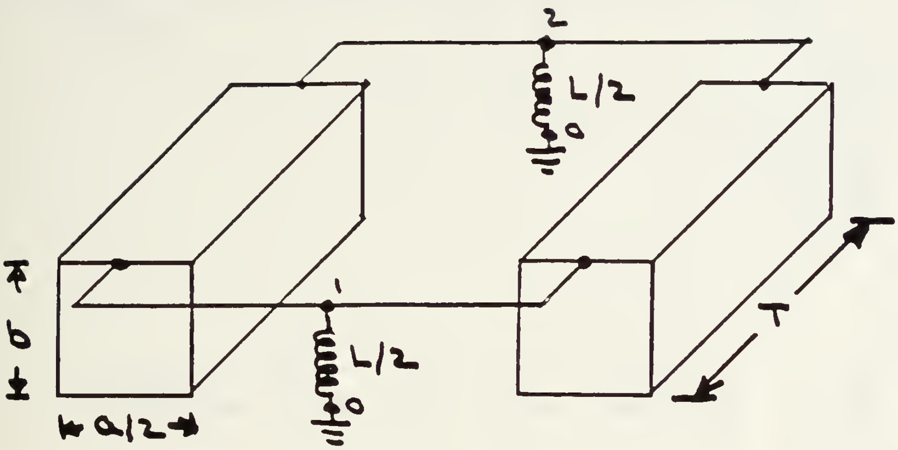

Figure 5. Circuit model of an inductive strip in finline.

```
! FILE NAME: T100.S2P

! USER: J. B. KNORR
! DATE: 4-88

! S-PARAMTER DATA FOR A T=.100 INCH INDUCTIVE STRIP CENTERED
! IN WR(90) WAVEGUIDE, W/b=ER2=1.

! S-PARAMETERS DERIVED FROM MILLER'S SMOOTHED EXPERIMENTAL DATA.

! GHZ S MA R 50

! F        S11           S21           S12           S22

08.0  .900  147.0  .435  57.0  .435  57.0  .900  147.0
09.0  .845  133.0  .534  43.0  .534  43.0  .845  133.0
10.0  .790  122.0  .613  32.0  .613  32.0  .790  122.0
11.0  .730  114.5  .683  24.5  .683  24.5  .730  114.5
12.0  .675  110.7  .737  20.7  .737  20.7  .675  110.7
```

Figure 6. TOUCHSTONE data file containing the measured scattering coefficients of an inductive strip of length T=100 mils centered in WR(90) waveguide.

```
! FILE NAME:  ST100MOD.CKT

! USER:       J. B. KNORR
! DATE:       5-13-88
! CIRCUIT:    MODEL OF .100 IN. INDUCTIVE STRIP IN WR(90) FINLINE.
!             W/b = 1, STRIP CENTERED.

! COMMENT:   THE MEASURED S-PARAMETERS FOR THIS STRIP ARE IN DATA
!            FILE T100.S2P AND WERE TAKEN FROM MILLER'S THESIS.

DIM
  FREQ GHZ
  RES OH
  IND NH
  CAP PF
  LNG MIL
  TIME PS
  COND /OH
  ANG DEG

VAR

EQN

CKT
   IND   1   0   L=20
   RWG   1   2   A=450   B=400   L=50   ER=1   RHO=1
   DEF2P 1   2   A
   A     1   2
   A     1   2
   A     3   2
   A     3   2
   DEF2P 1   3   STRIPMOD

   S2PA  1   2   0   T100.S2P
   DEF2P 1   2   STRIP100

   RWGT  1       A=900   B=400   ER=1   RHO=1
   DEF1P 1       WEDGE

TERM
   STRIPMOD   WEDGE   WEDGE

PROC

OUT
   STRIPMOD   S11   SC2
   STRIPMOD   MAG[S11]   GR1
   STRIPMOD   ANG[S11]   GR2
   STRIP100   S11   SC2
   STRIP100   MAG[S11]   GR1
   STRIP100   ANG[S11]   GR2

FREQ
  SWEEP   8   12   .1

GRID
  RANGE   8   12   1
  GR1     0   1   .1
  GR2     90  180  10

OPT

TOL
```

Figure 7. TOUCHSTONE circuit file containing the model for an inductive strip of length T=100 mils centered in WR(90) waveguide.

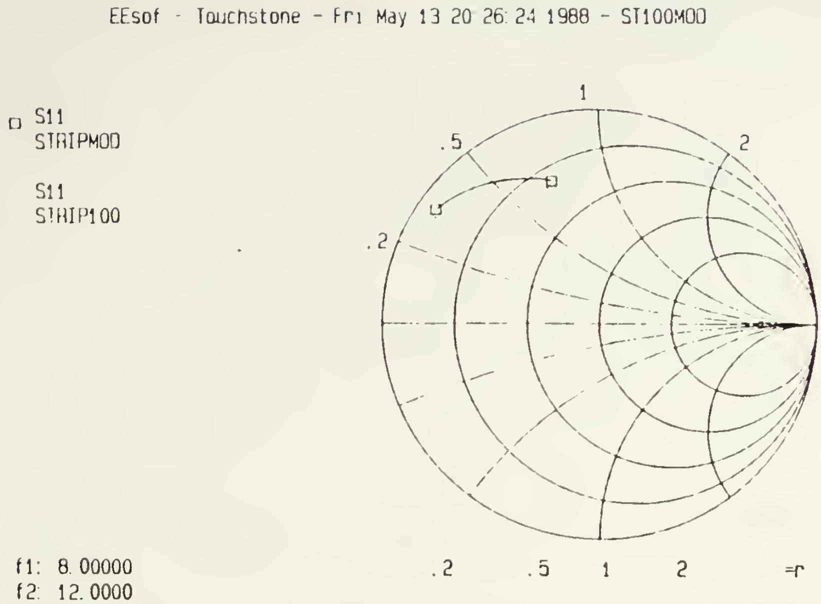

Figure 8. Smith Chart plot of measured and predicted values of s_{11} for a T=100 mil inductive strip centered in WR(90) waveguide. Model inductance L=20 nH.

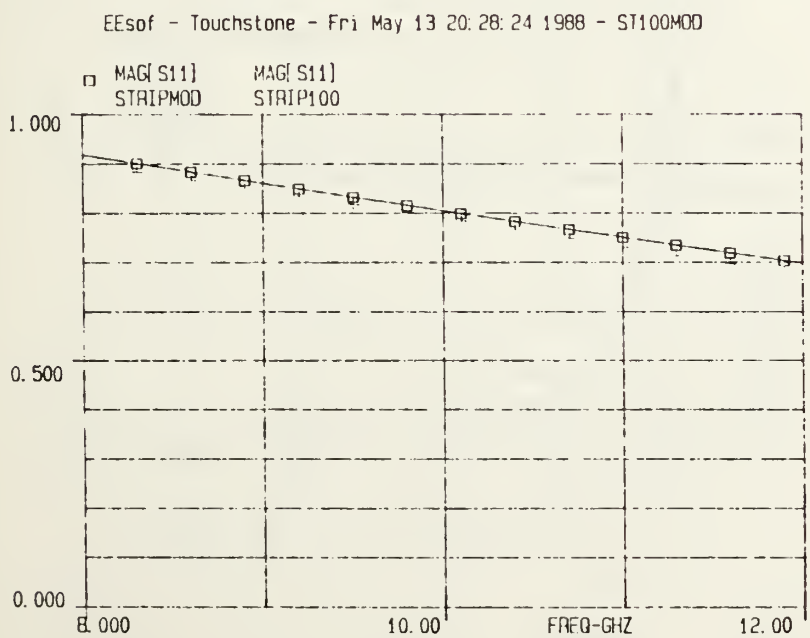

Figure 9. Measured and predicted values of $/s_{11}/$ vs. frequency for a T=100 mil inductive strip centered in WR(90) waveguide. Model inductance L=20 nH.

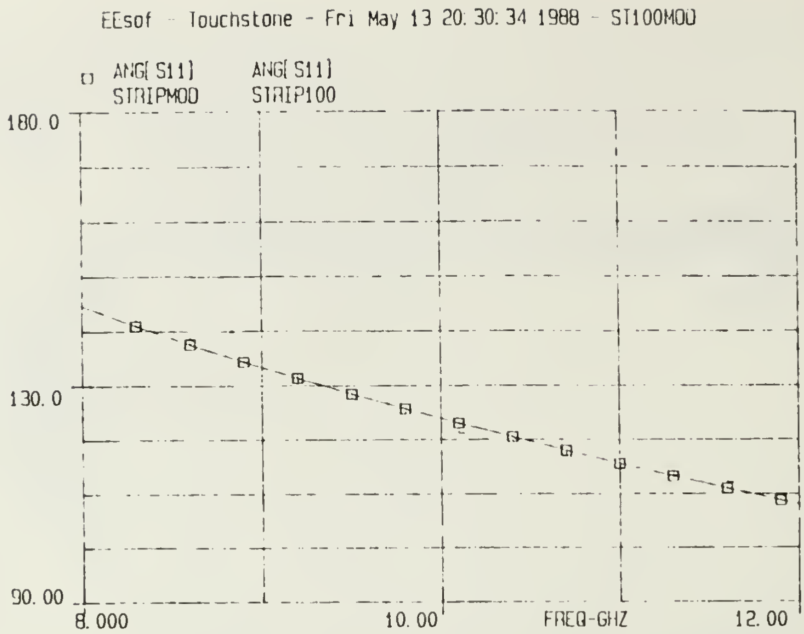

Figure 10. Measured and predicted values of θ_{11} vs. frequency for a T=100 mil inductive strip centered in WR(90) waveguide. Model inductance L=20 nH.

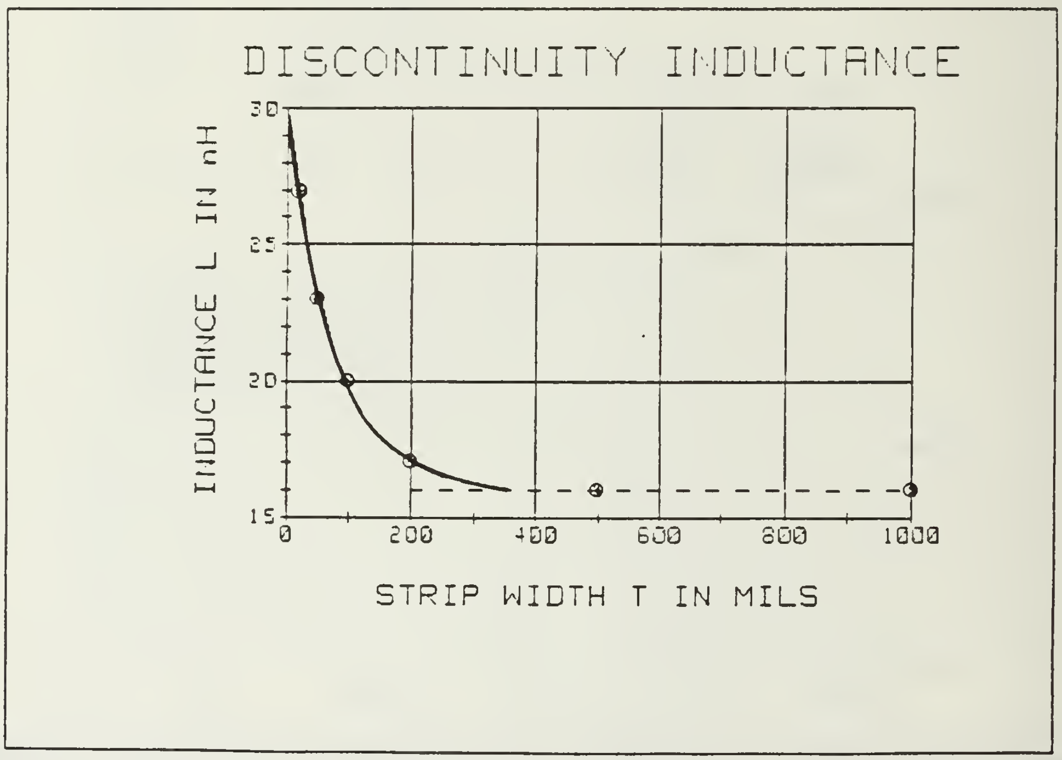

Figure 11. Model inductance L vs, strip length T for inductive strips centered in WR(90) waveguide.

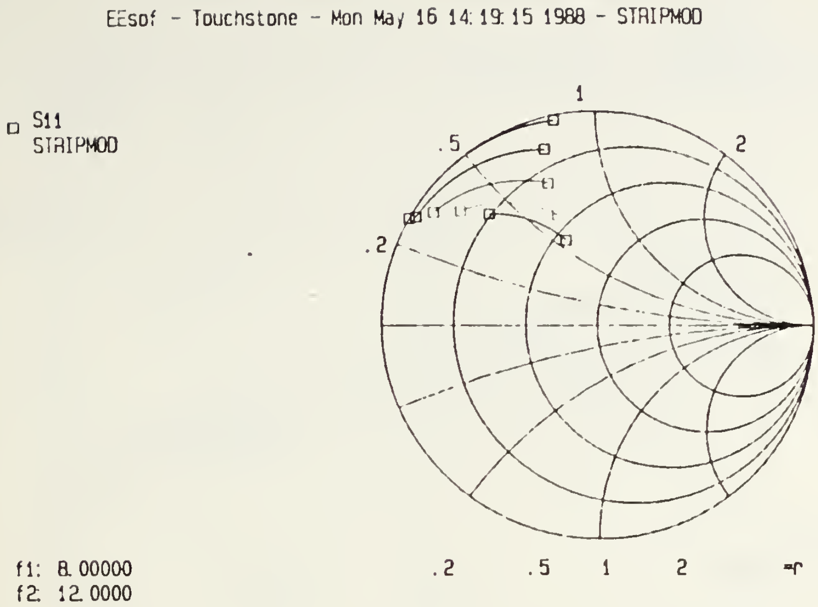

Figure 12. Smith Chart plot of s_{11} for inductive strips of length T=20, 50, 100, 200 and 500 mils centered in WR(90) waveguide.

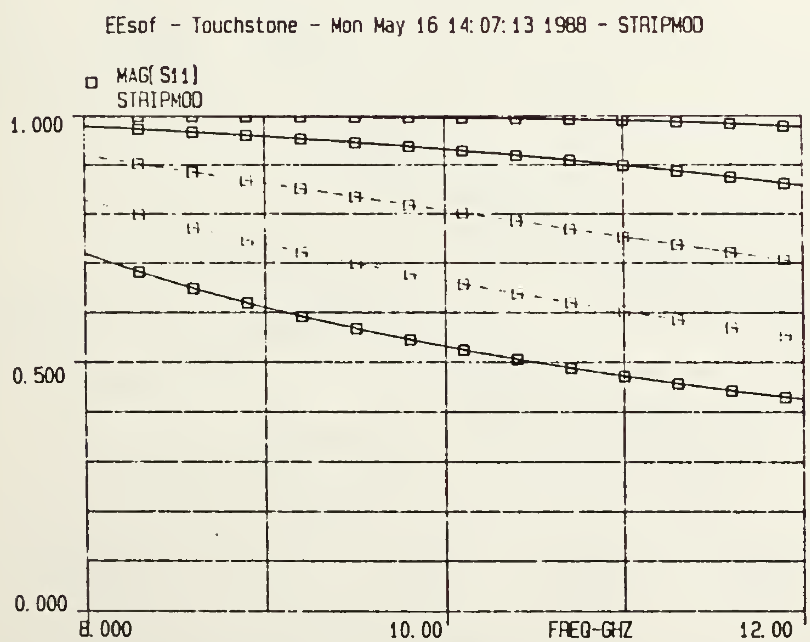

Figure 13. $/s_{11}/$ vs. frequency for inductive strips of length T=20, 50, 100, 200 and 500 mils centered in WR(90) waveguide.

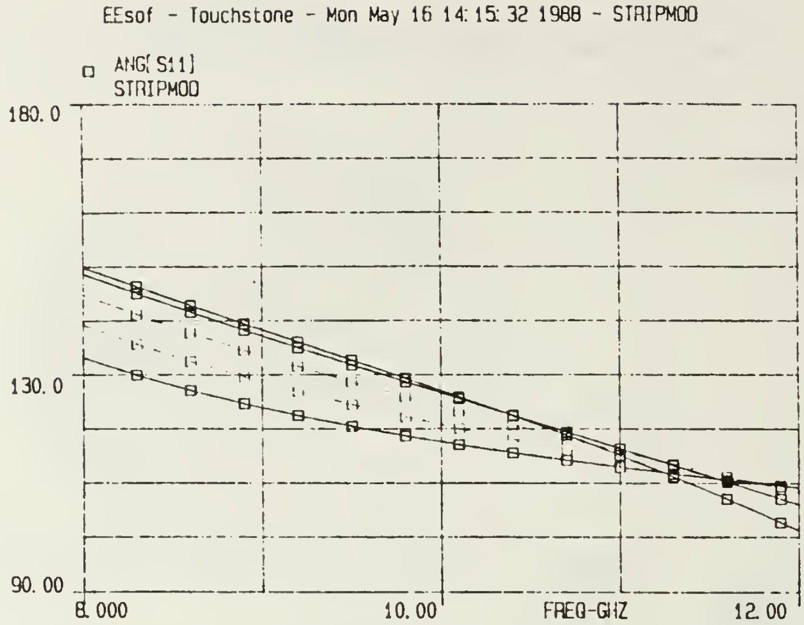

Figure 14. θ_{11} vs. frequency for inductive strips of length T=20, 50, 100, 200 and 500 mils centered in WR(90) waveguide.

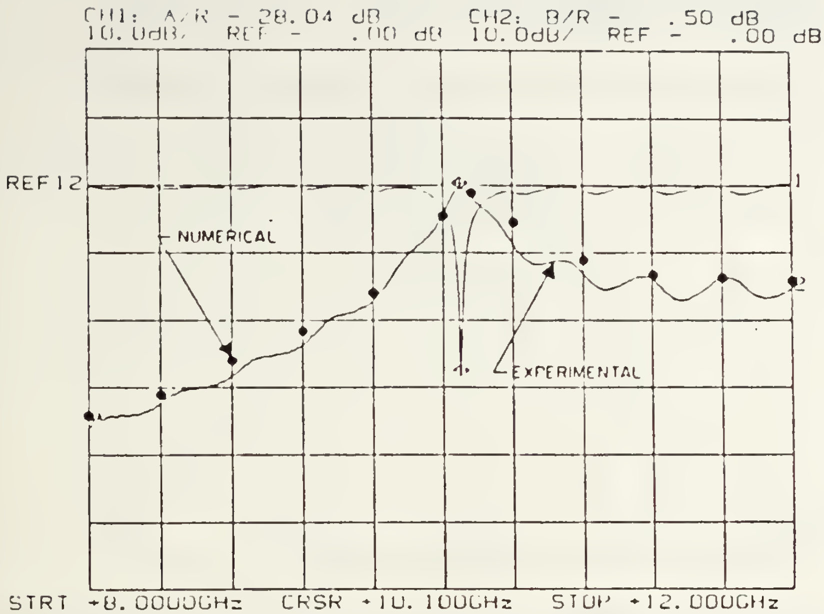

Figure 15. Insertion loss and return loss vs. frequency for an. X-band finline resonator. From [6].

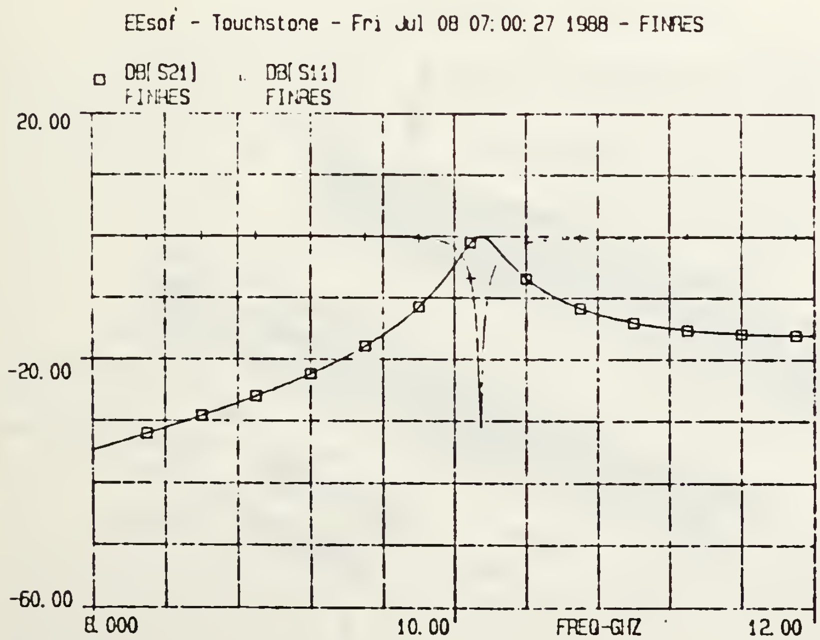

Figure 16. Insertion loss and return loss vs. frequency for an X-band finline resonator. Response computed using TOUCHSTONE with the circuit model for the inductive strip.

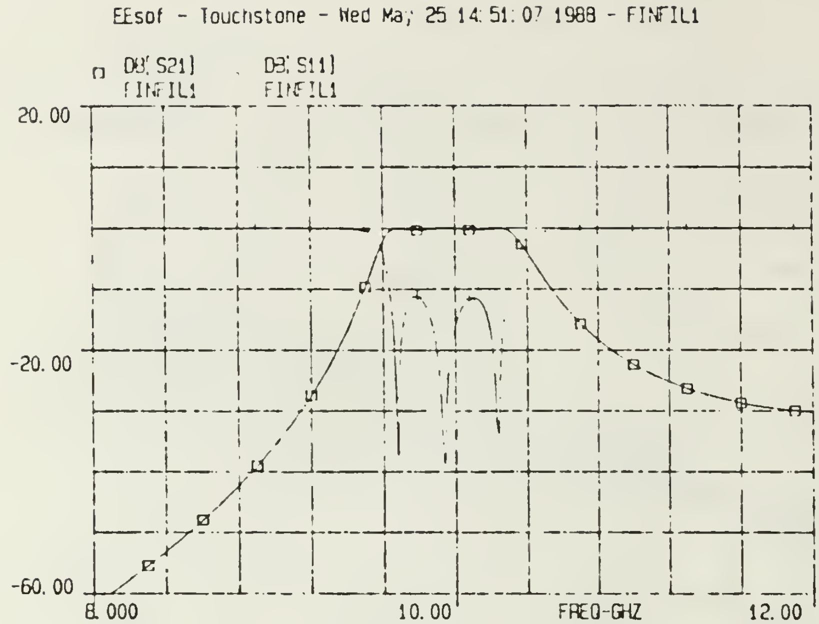

Figure 17. Insertion loss and return loss vs. frequency for a 3 resonator finline filter with equal ripple response. Response computed using TOUCHSTONE with the circuit model for the inductive strip.

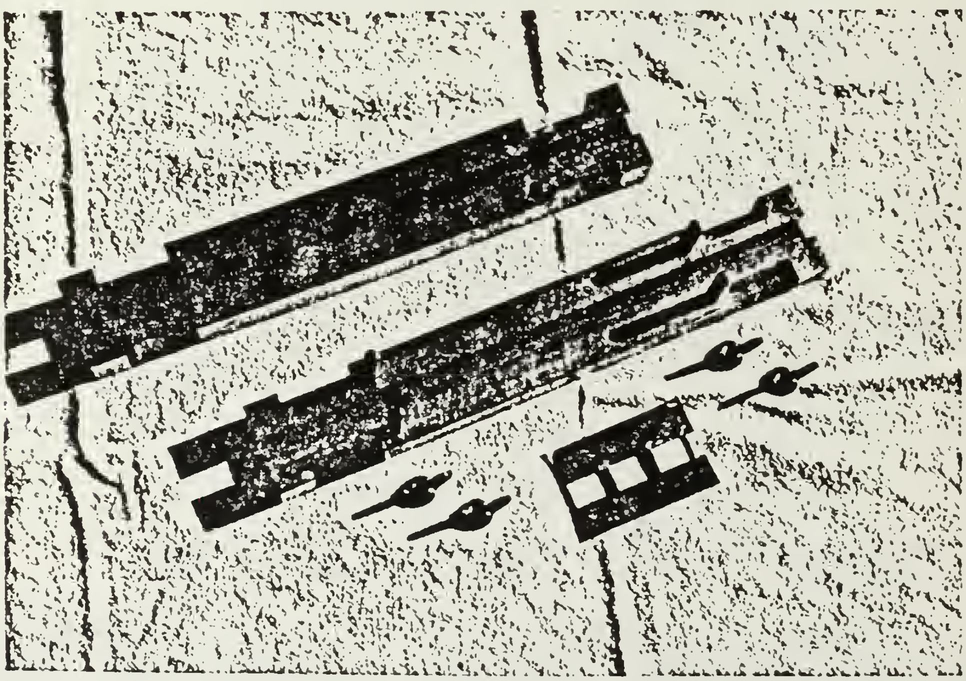

Figure 18. Photograph of the finline filter simulated in the circuit file FINFIL1A.CKT contained in Appendix 3.

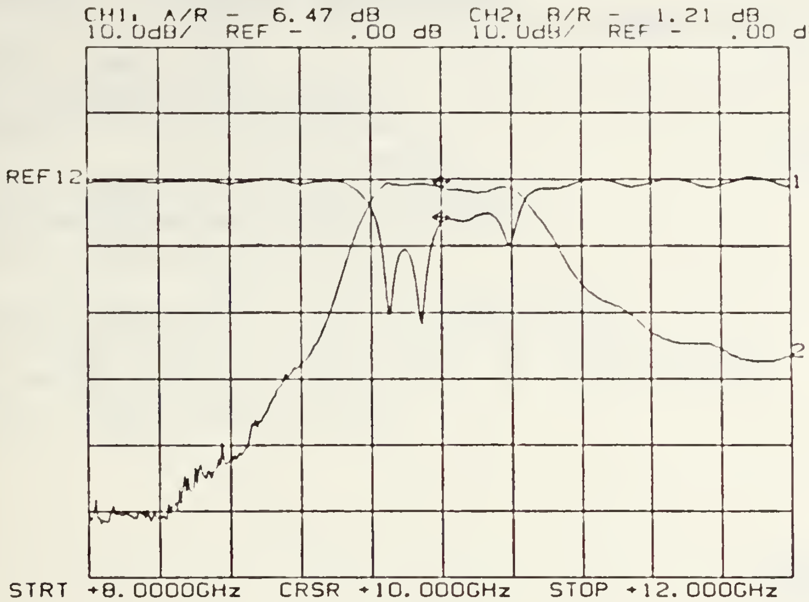

Figure 19. Measured insertion loss and return loss vs. frequency for the finline filter shown in Figure 18. Response measured using the HP8756 Scalar Network Analyzer.

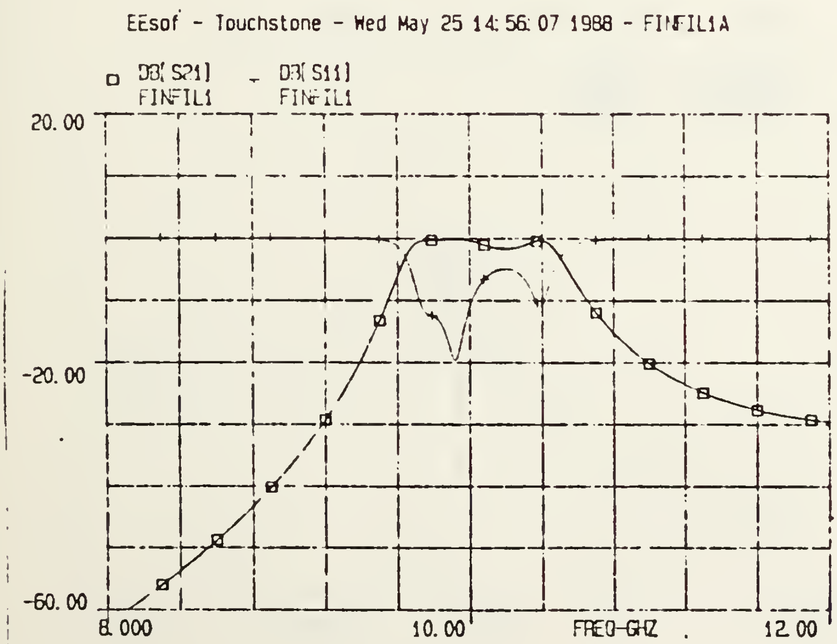

Figure 20. Predicted insertion loss and return loss vs. frequency for the finline filter shown in Figure 18. Response computed using TOUCHSTONE with the circuit model for the inductive strip.

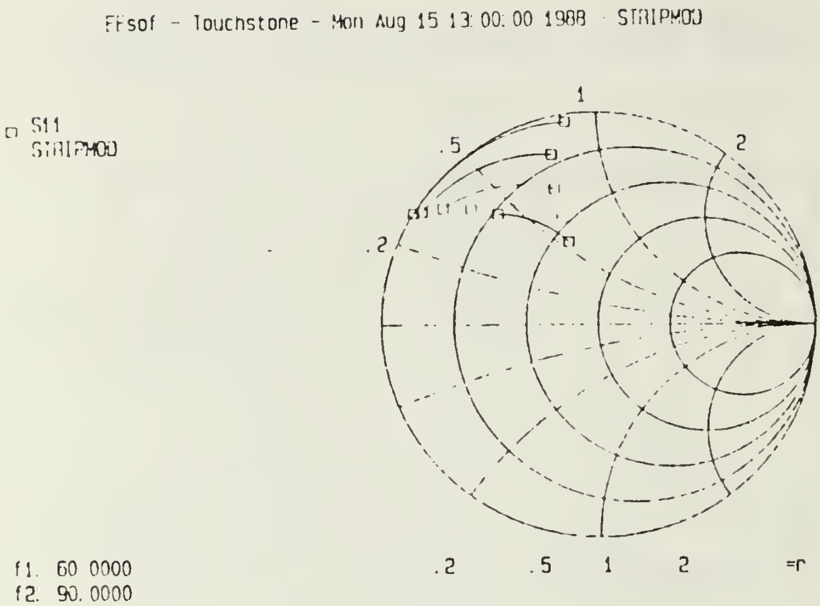

Figure 21. Predicted values of s_{11} for inductive strips in WR(12) waveguide. T/a=.02, .05, .10, .20 and .50. Frequency range 60-90 GHz.

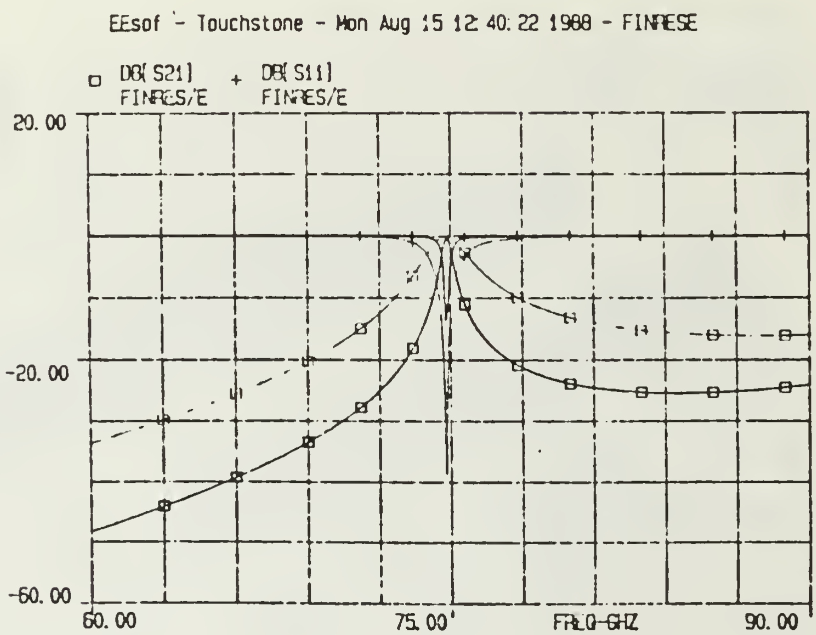

Figure 22. Predicted response of a 75 GHz WR(12) waveguide resonator for two different strip widths, T=30mils and T=50 mils. Strips separated by 72 mils. Response computed using TOUCHSTONE

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